Development of Yin-Yang Grid Global Model Using a New Dynamical Core ASUCA.

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introduction

The Japan Meteorological Agency (JMA) has been exploring next generation global numerical weather prediction (NWP) model, namely non-hydrostatic global NWP model. The effort was initiated in 2009. The current candidates are:

- <u>a finite volume method yin-yang grid model using a regional dynamical core developed at Numerical Prediction Division of JMA (ASUCA-GLOBAL)</u>
- a finite volume method icosahedral-grid model developed by JAMSTEC, Tokyo-Univ., and RIKEN (NICAM)
- a semi-implicit semi-Lagrangian spectral model using Double Fourier series developed by Meteorological Research Institute of JMA
- a non-hydrostatic expansion of the current semi-implicit semi-Lagrangian spherical harmonics spectral model of JMA

contents

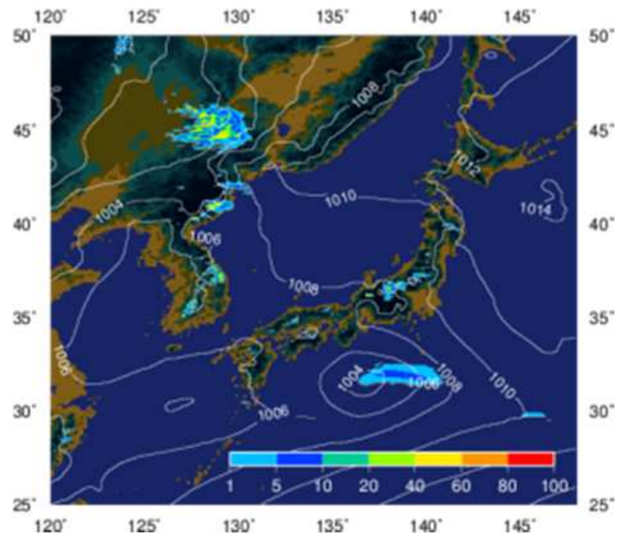
- ASUCA and its techniques used in dynamics
- ASUCA-GLOBAL and its grid design
- Results of a ASUCA-GLOBAL forecast experiment
- Execution times and scalability
- Future plan
- Summary

ASUCA

A non-hydrostatic model with the finite volume method: ASUCA

- ✓ Horizontally explicit and vertically implicit treatment for acoustic waves (HEVI)
- ✓ the 3-step Runge-Kutta time integration method by Wicker and Skamarock (2002)
- ✓ a flux limiter proposed by Koren (1993)
- ➢ without any numerical diffusion and viscosity to stabilize the calculation
- ✓ general coordinate transformations, which allows us to use the Lambert conformal conic projection and the latitude - longitude projection
- ✓ ASUCA will provide 9 hour forecasts around Japan every hour, with a horizontal resolution of 2 km in the near future.

a 12hour forecast from 00UTC 18 June 2013 by the latitude-longitude grid version of ASUCA. Distributions of sea level pressure (hPa) for 12UTC 18 June 2013 (contour), and 6hour precipitation (mm) by 12UTC 18 June 2013 (shade).



flux limiter by Koren(1993)

The total flux used in the finite volume method using Arakawa-C grid is

$\partial p_i/\partial t = (F_{i-1/2} - F_{i+1/2})/\Delta x$,

where p_i is a predictor at i th grid, $F_{i-1/2}$ and $F_{i+1/2}$ are the flux of p at both sides of each grid, and Δx is size of the grid. Flux limiter b is used to estimate flux,

$F_{i+1/2} = u_{i+1/2} [p_i + b_{i+1/2} (p_{i+1} - p_i) /2]$, $F_{i-1/2} = u_{i-1/2} [p_{i-1} + b_{i-1/2} (p_i - p_{i-1})/2]$.

Koren (1993) defined his limiter "b" as

$b_{i+1/2} = \max[0, \min(2r_i, (r_i + 2)/3, 2)]$, $b_{i-1/2} = \max[0, \min(2r_{i-1}, (r_{i-1} + 2)/3, 2)]$.

where

$r_i = (p_i - p_{i-1})/(p_{i+1} - p_i)$, $r_{i-1}=(p_{i-1} - p_{i-2})/(p_i - p_{i-1})$.

When r is large enough (i.e. steep gradient of p), estimated flux approaches to the 1st order upwind scheme:

$F_{i+1/2} = \{u_{i+1/2} (p_i + p_{i+1}) + |u_{i+1/2}| (p_i - p_{i+1}) \}/2$,

$F_{i-1/2} = \{u_{i-1/2} (p_{i-1} + p_i) + |u_{i-1/2}| (p_{i-1} - p_i) \}/2$.

Runge-Kutta scheme by Wicker and Skamarock (2002)

Wicker and Skamarock (2002),

$p^* = p^t + (\partial p^t/\partial t)\ \Delta t/3$

$p^{**} = p^t + (\partial p^*/\partial t)\ \Delta t/2$

$p^{t+\Delta t} = p^t + (\partial p^{**}/\partial t)\ \ \Delta t$

Runge-Kutta 3rd Method,

$p^* = p^t + (\partial p^t/\partial t)\Delta t/2$

$p^{**} = p^t + (\partial p^*/\partial t)\ 2\Delta t - (\partial p^t/\partial t)\ \Delta t$

$p^{t+\Delta t} = p^t + (\partial p^t/\partial t\ + 4\ \partial p^*/\partial t + \partial p^{**}/\partial t)\ \Delta t/6$

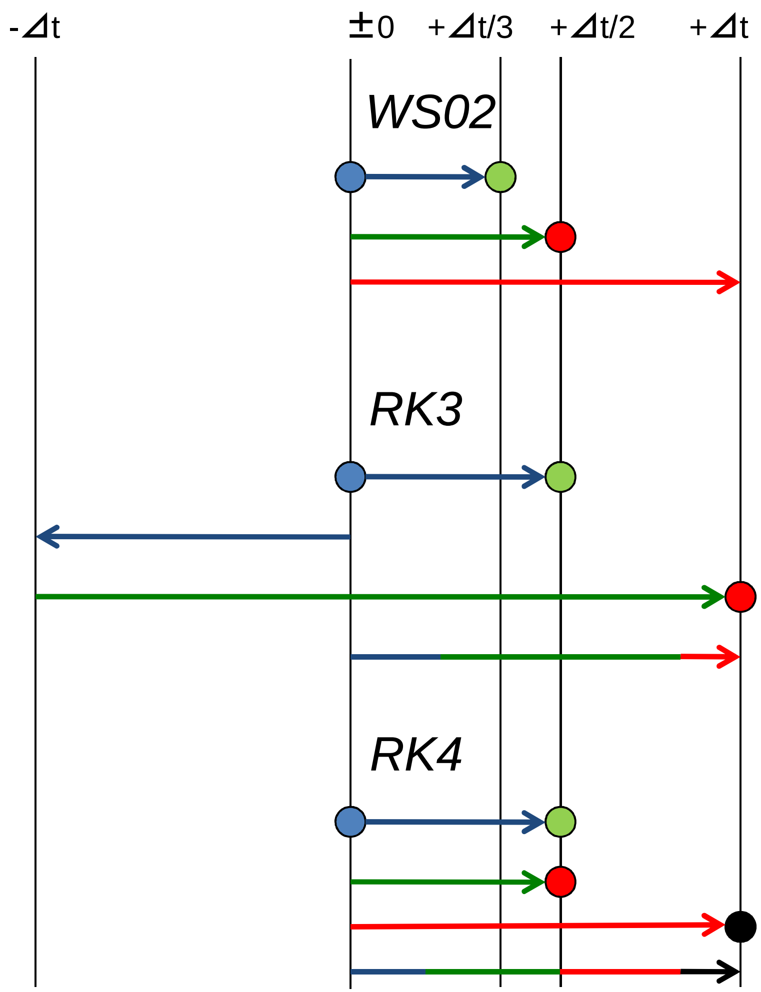
Runge-Kutta 4th Method,

$p^* = p^t + (\partial p^t/\partial t)\Delta t/2$

$p^{**} = p^t + (\partial p^*/\partial t)\Delta t/2$

$p^{***} = p^t + (\partial p^{**}/\partial t)\Delta t$

$p^{t+\Delta t} = p^t+(\partial p^t/\partial t+2\partial p^*/\partial t+2\partial p^{**}/\partial t+\partial p^{***}/\partial t)\ \Delta t/6$



Williamson et al. (1992) test cast 1

α=0, Courant number:1.0, after one period

L_1 norm: $\int|\rho_{fcst} - \rho_{true}|ds/\int\rho_{true}\, ds$

WS02	RK3	RK4
8.3×10^{-4}	6.3×10^{-4}	5.6×10^{-4}

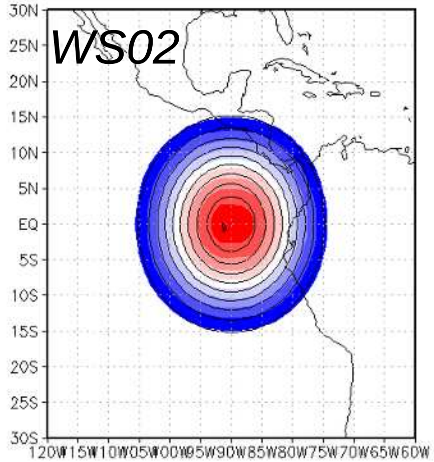
L_2 norm: $\left(\int(\rho_{fcst} - \rho_{true})^2 ds / \int\rho_{true}^2\, ds\right)^{1/2}$

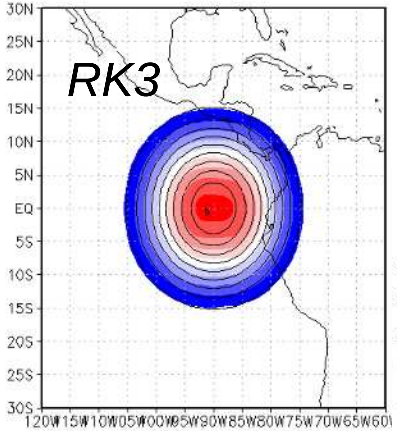
WS02	RK3	RK4
3.6×10^{-2}	4.2×10^{-2}	4.4×10^{-2}

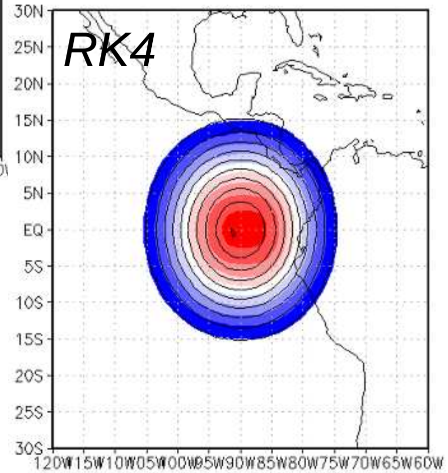
L_∞ norm: $\max|\rho_{fcst} - \rho_{true}| / \max|\rho_{true}|$

WS02	RK3	RK4
4.8×10^{-2}	5.8×10^{-2}	6.4×10^{-2}

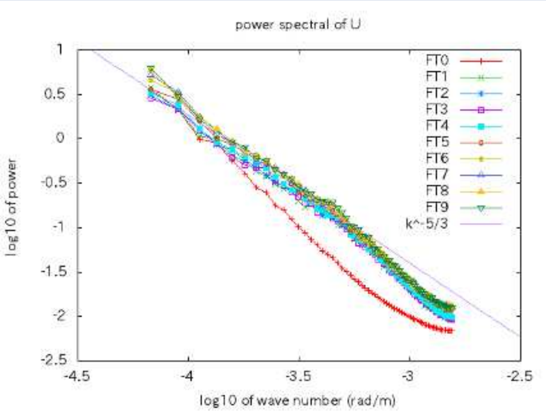
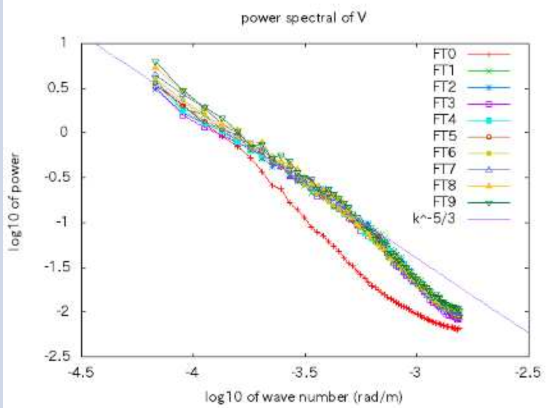
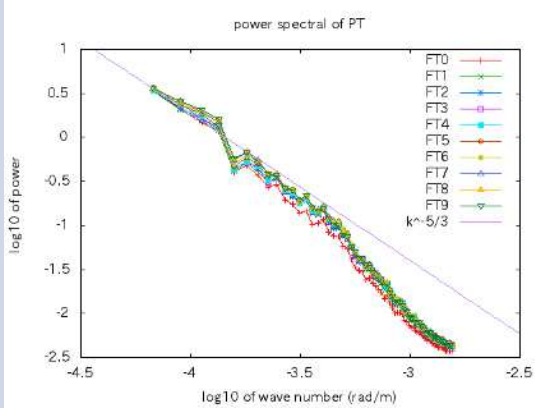
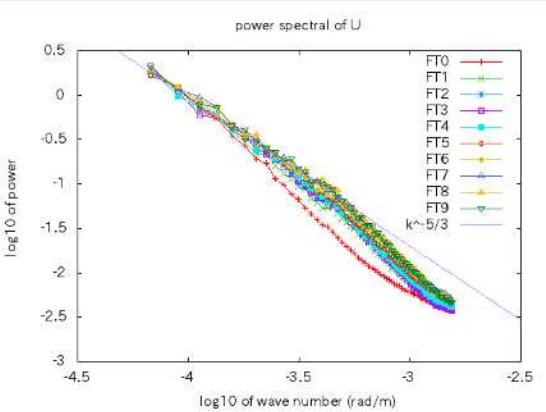
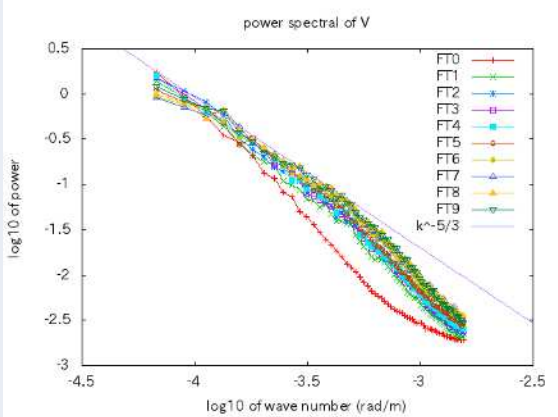
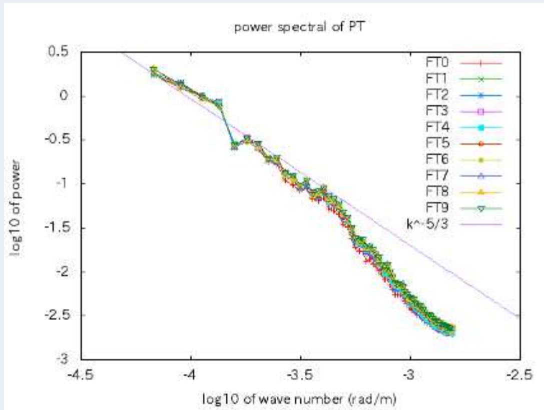
Wicker and Skamarock (2002) seems simple, but shows better results in L_2 and L_∞ scores.







Power Spectrum Density of zonal and meridional wind speed, and potential temperature at Layer-13 (near 850hPa) from regional forecasts for east Japan

	Zonal Wind Speed	Meridional Wind Speed	Potential Temperature
A			
B			

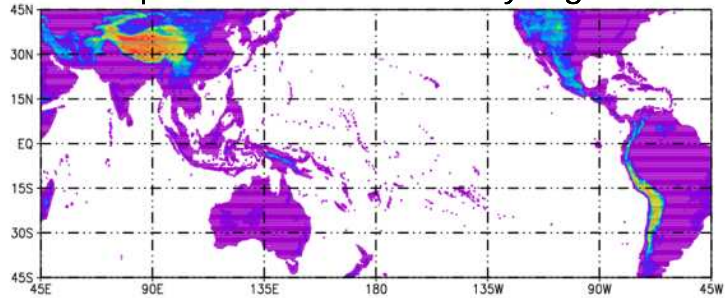
A: 8 forecasts during 19 – 25, July, 2011,   B: 7 forecasts during 24 – 30, August, 2011

ASUCA-GLOBAL

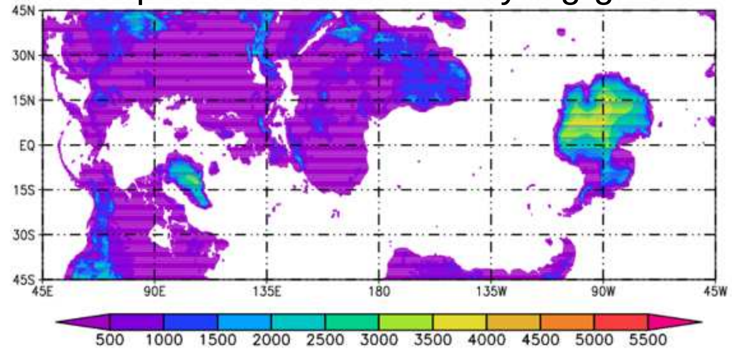
Grid Design

- ✓ Grid design used is the same as one by Baba et. al (2010)
- ✓ The boundary region exchange method (BRE) is adopted without using numerical diffusion, viscosity, and filters
- ➢ The amount of information to be exchanged at the boundary is proportional to length of the circumference (not area) of each grid.

Computational Domain for yin-grid



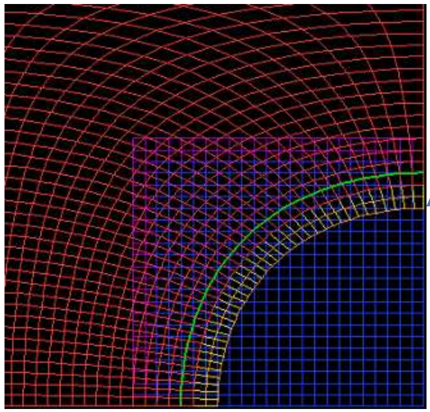
Computational Domain for yang-grid

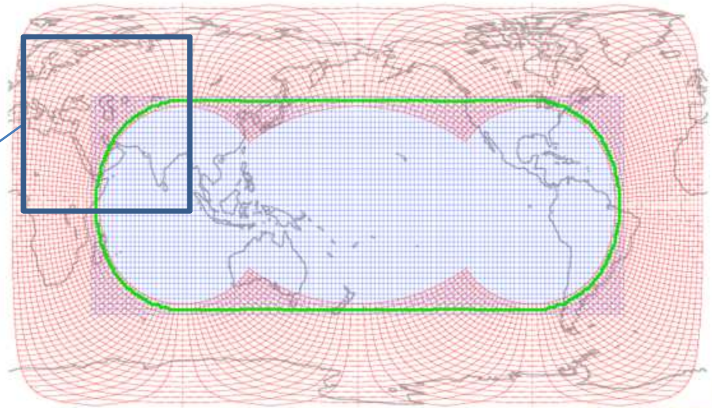


Boundary Region Exchange (BRE):

The blue grid (yin-grid) receives information at the purple region, and the red grid (yang - grid) receives at the yellow area. Forecasts for the overlapped area between the purple and yellow areas are calculated in both grids.

The border is the green line.

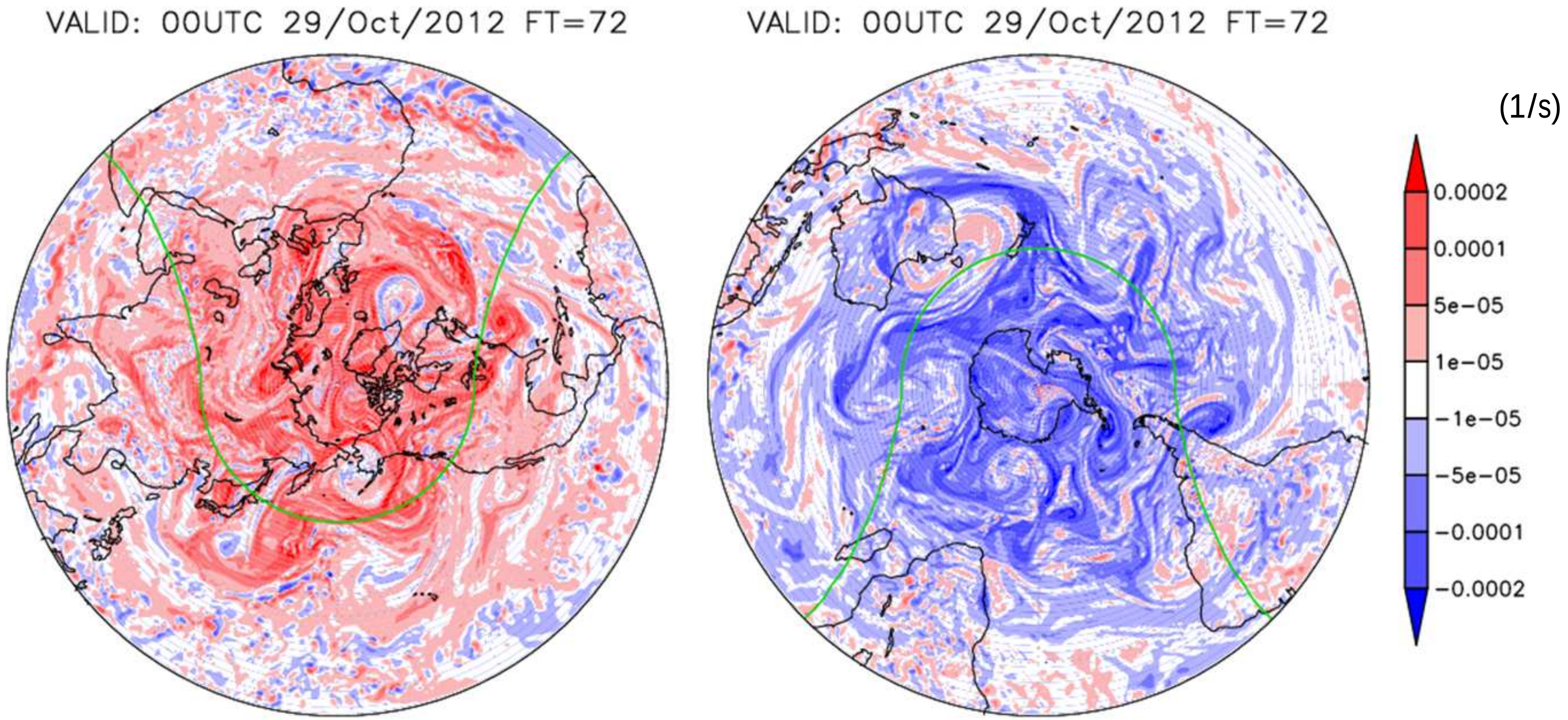




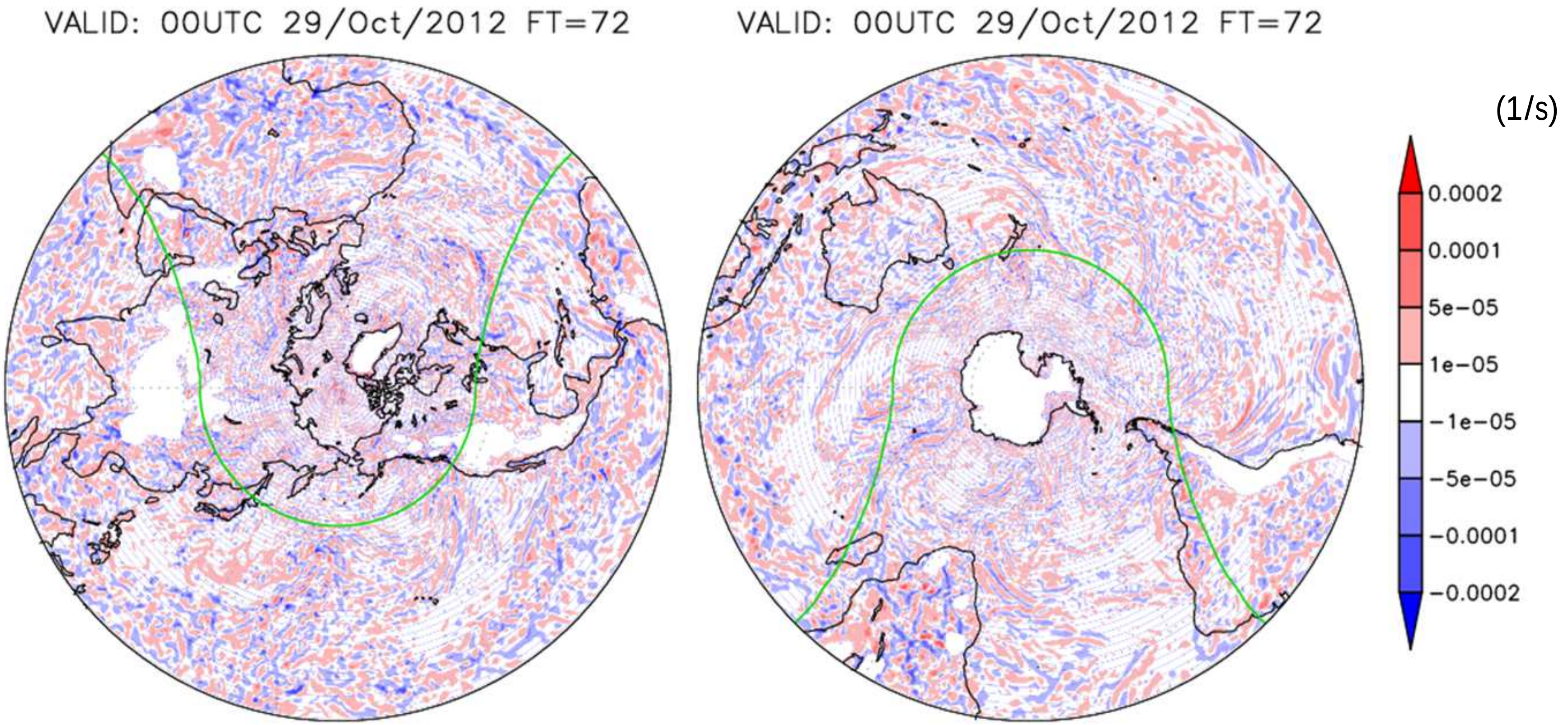
Forecast example by ASUCA-GLOBAL

- Spatial resolution :
  - Horizontal: 0.25deg (1080 x 360 x 2 grids)
  - Vertical: stretched 57 layers up to around 20,000m above sea level
- Time step interval (outer) : 60sec
- Forecast Period: 72hours (4320steps)
- Physical processes used for regional forecast experiments are adopted
- Initial data are produced using JMA's operational global forecast
- Initial time: 00UTC 26 Oct 2012

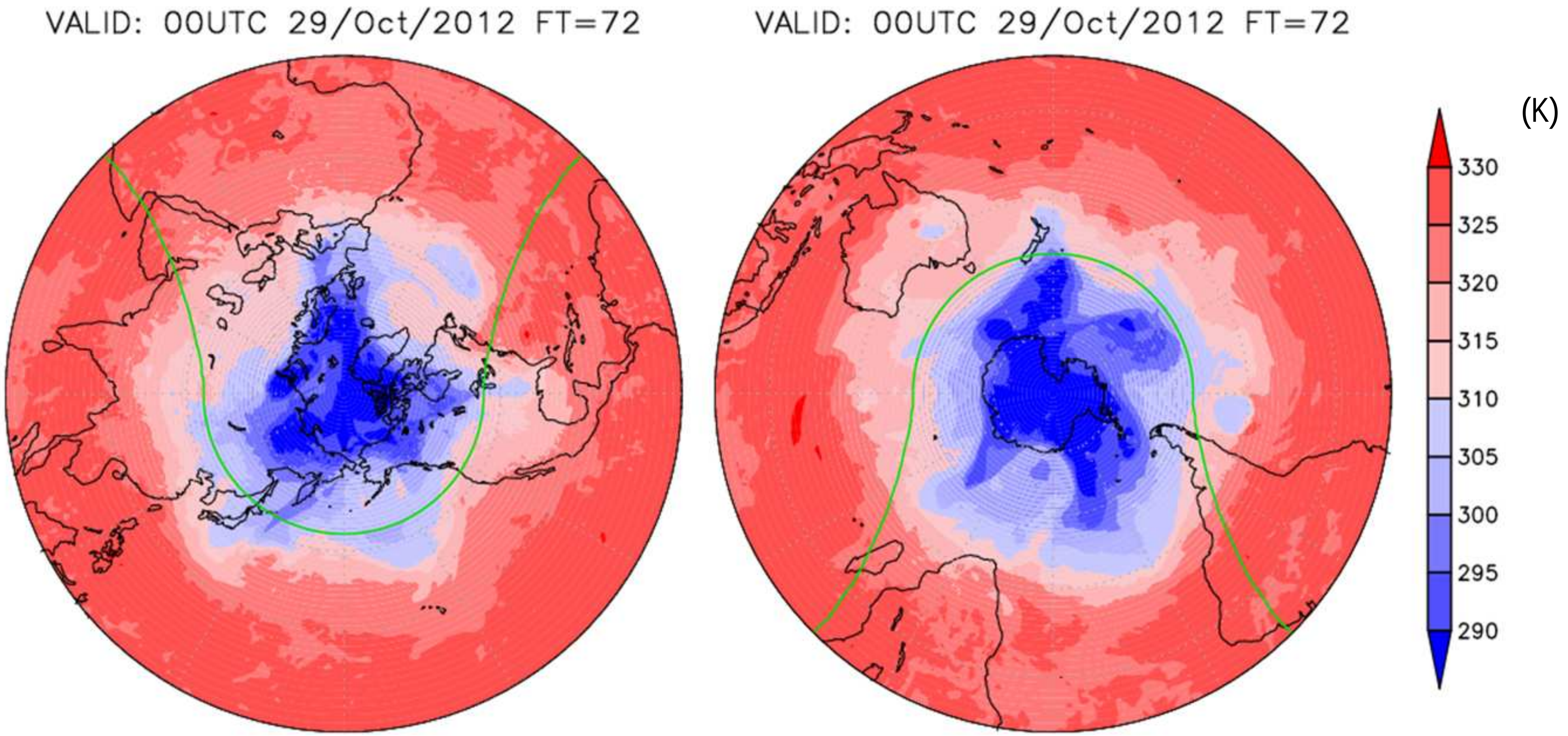
Absolute Vorticity at 500hPa



Divergence at 850hPa



Potential Temperature at 500hPa



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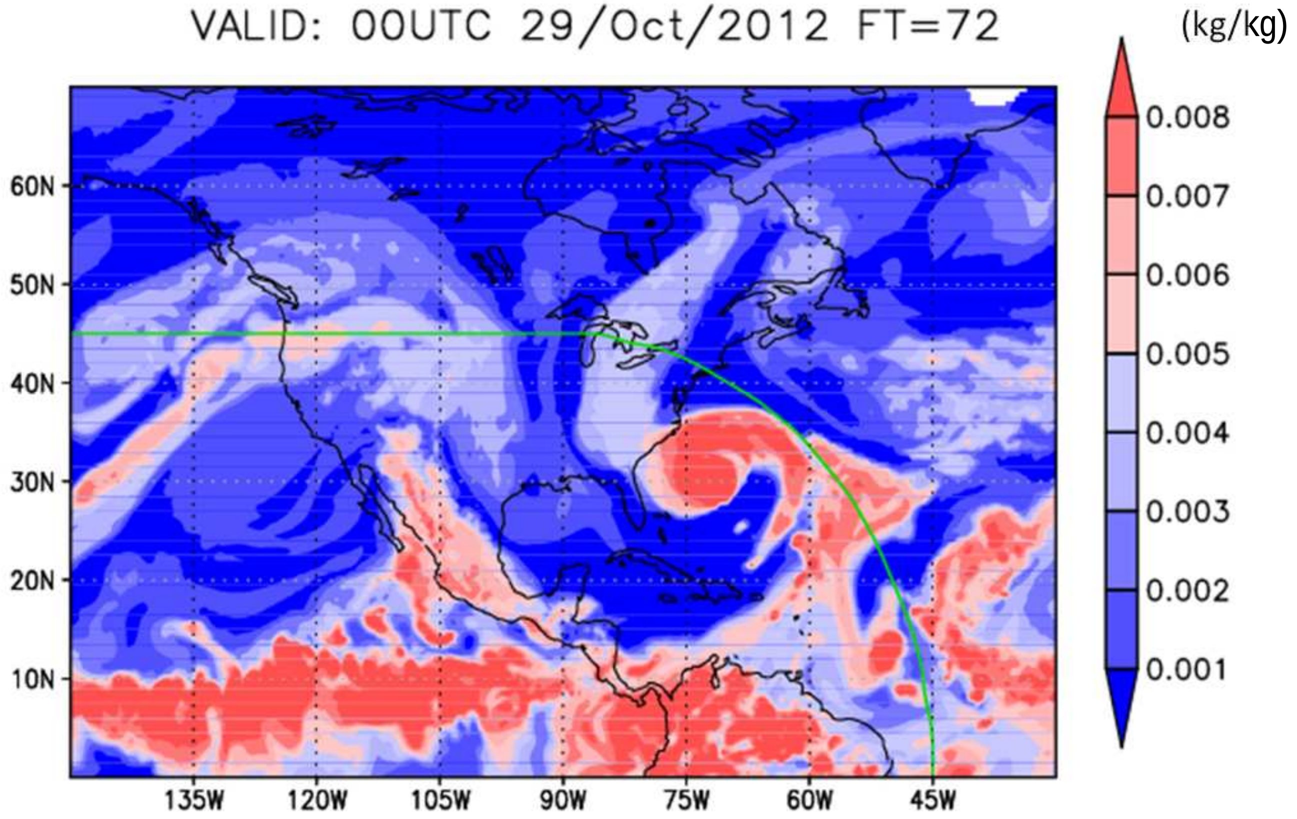
Specific Humidity at 700hPa



Execution time at HITACH SR16000M1 of JMA

Hitachi SR16000 Model M1

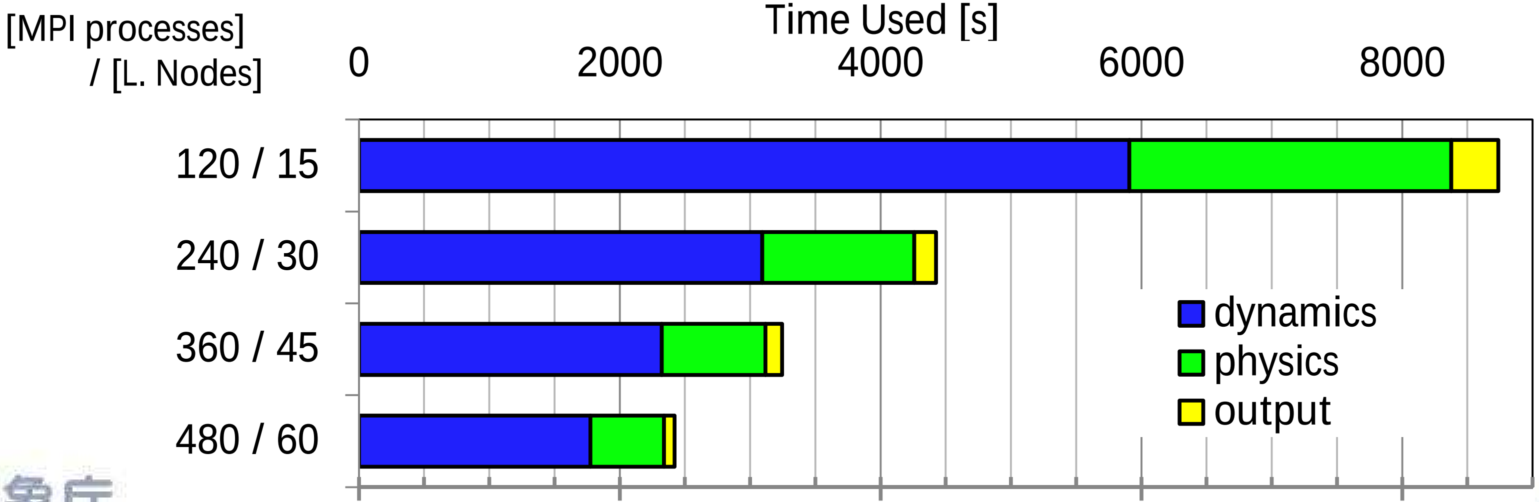
- Logical Maximum Performance: 847 TFLOPS
- Node Number: 108 (864 logical node)

Power 7 (3.83GHz, 8core) x 4 (socket) x 8 (logical node)

x 54 (physical node) x 2 (main/sub)

- Memory: 108TB

72 hour forecast (0.25 deg, ⊿t=60sec) execution time

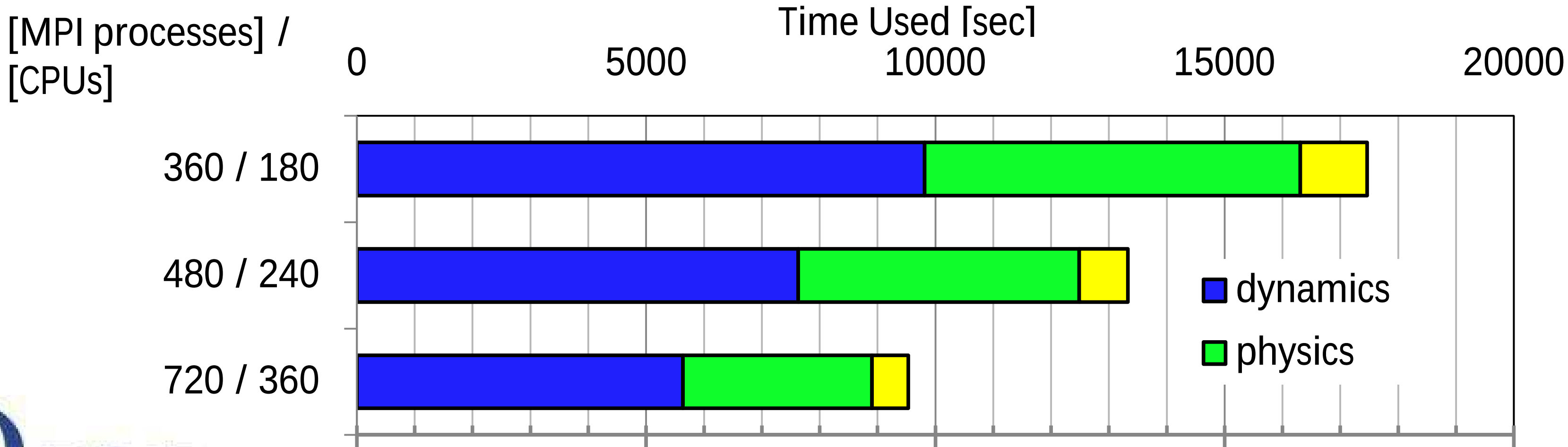


Execution time at K-computer of Japanese HPCI

K-computer

- 8.162PFLOPS (LINPACK benchmark)
  @ June 2011
- SPARC 64 VIIfx (8core 128GFLOPS)
  x 88,000 (CPU)

72 hour forecast (0.25deg grid, ⊿t=60sec) execution time

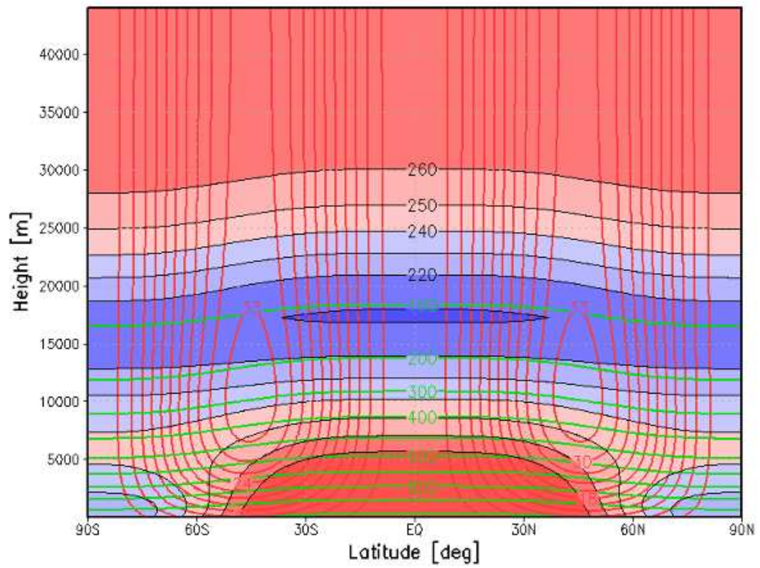


Future Plan

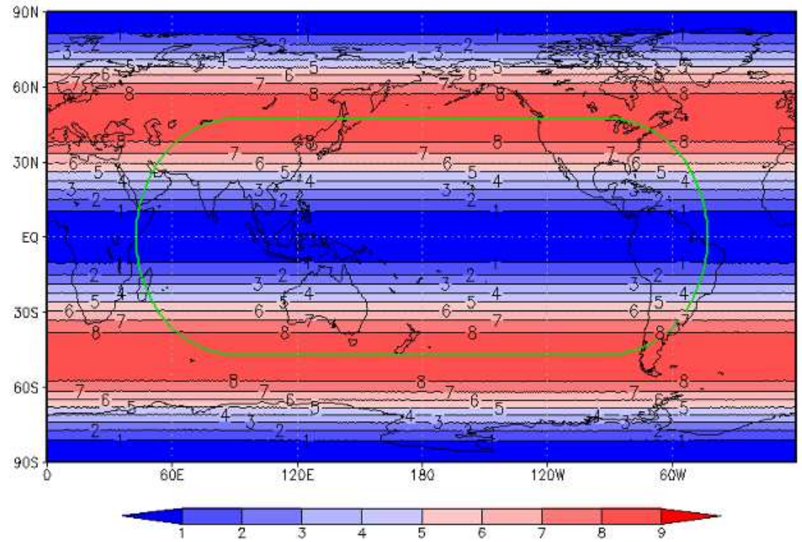
Comparison of the dynamical cores using Jablonowski and Williamson (2006) test at K-computer

- ASUCA-GLOBAL
- semi-implicit semi-Lagrangian DF spectral model
- A finite volume method Icosahedral C-grid model by Tokyo Univ.

<u>Initial state without the perturbation proposed by Jablonowsk and Williamson (2006)</u>



Potential Temperature (shade and black contour, K), pressure (green contour, hPa), and zonal wind speed (red contour, m/s).



zonal wind speed (red contour, m/s) at the lowest level (29m above mean sea level)

Summary

A finite volume method Yin-Yang grid model ASUCA-GLOBAL has been examined

- a regional non-hydrostatic dynamical core ASUCA is adopted to execute global forecasts
- 0.25 deg grid forecast results seem reasonable (to some extent)
- Execution results at super computers suggest that ASUCA-GLOBAL has a good scalability
- Jablonowski and Williamson (2006) test will be examined at Kei Computer in the near future

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Thank you